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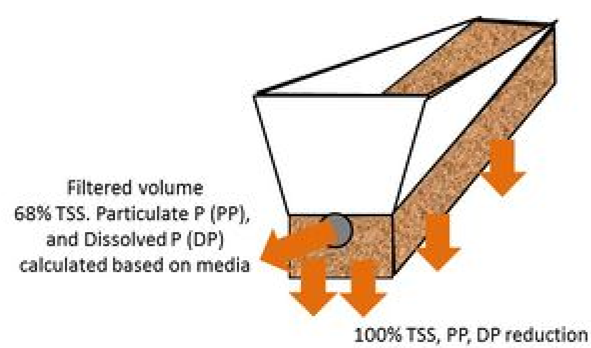
Information on pollutant removal by BMPs



Schematic of pollutant removal mechanisms for a dry swale with an underdrain.

This stormwater manual contains information on pollutant removal for a limited number of pollutants. Links to more detailed or additional information are provided below. Users should be aware there is considerable information on pollutant removal in the literature and on-going research on the topic of pollutant removal by stormwater **best management practices** (BMPs). The information in this manual is therefore subject to change and often reflects ranges found in the literature rather than specific values. To see updates to credits, see the page called Updates to credits and pollutant removal values.

The following table provides a summary of median pollutant removal for BMPs. These represent recommended values to be used in models, loading estimates, etc. However, pollutant

removal is a function of many factors, including design, construction, and maintenance of the BMP; quality of incoming stormwater; time of year; rainfall and watershed characteristics; and so on. The user is encouraged to read the section called Factors affecting pollutant removal (https://stormwater.pca.state.mn.us/index.php?title=Information_on_pollutant_removal_by_BMPs#Factors_affecting_pollutant_removal).

Median pollutant removal percentages for several stormwater BMPs. Sources (http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs#References). More detailed information and ranges of values can be found in other locations in this manual, as indicated in the table. NSD - not sufficient data. **NOTE**: Some filtration bmps, such as biofiltration, provide some infiltration. The values for filtration practices in this table are for filtered water.
Link to this table

Practice	TSS	TP	PP	DP	TN	Metals[1]	Bacteria	Hydrocarbons
Infiltration (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_Best_Management_Practices)[2]	[3]	[3]	[3]	[3]	[3]	[3]	[3]	[3]
Biofiltration and Tree trench/tree box with underdrain	80	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	50	35	95	80
Sand filter	85	50	85	0	35	80	50	80
Iron enhanced sand filter (http://stormwater.pca.state.mn.us/index.php/Iron_enhanced_sand_filter_%28Minnesota_Filter%29)	85	65 or 74[6]	85	40 or 60[6]	35	80	50	80

Practice	TSS	TP	PP	DP	TN	Metals[1]	Bacteria	Hydrocarbons
Dry swale (no check dams)	68	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	35	80	0	80
Wet swale (no check dams)	35	0	0	0	15	35	35	NSD
Constructed wet ponds[4, 5]	84	50 or 68[5]	84	8 or 48[5]	30	60	70	80
Constructed wetlands	73	38	69	0	30	60	70	80
Permeable pavement (with underdrain)	74	41	74	0	NSD	NSD	NSD	NSD
Green roofs	85	0	0	0	NSD	NSD	NSD	NSD
Vegetated (grass) filter (https://stormwater.pca.state.mn.us/index.php?title=Overview_for_pretreatment_vegetated_filter_strips)	68	0	0	0	NSD	NSD	NSD	NSD
Harvest and reuse (https://stormwater.pca.state.mn.us/index.php?title=Calculating_credits_for_stormwater_and_rainwater_harvest_and_use/reuse)	Removal is 100% for captured water that is infiltrated. For water captured and routed to another practice, use the removal values for that practice.							

TSS=Total suspended solids, TP=Total phosphorus, PP=Particulate phosphorus, DP=Dissolved phosphorus, TN=Total nitrogen

[1]Data for metals is based on the average of data for zinc and copper

[2]BMPs designed to infiltrate stormwater runoff, such as infiltration basin/trench, bioinfiltration, permeable pavement with no underdrain, tree trenches with no underdrain, and BMPs with raised underdrains.

[3]Pollutant removal is 100 percent for the volume infiltrated, 0 for water bypassing the BMP. For filtered water, see values for other BMPs in the table.

[4]Dry ponds do not receive credit for volume or pollutant removal

[5]Removal is for Design Level 2 (https://stormwater.pca.state.mn.us/index.php?title=Requirements,_recommendations_and_information_for_using_stormwater_pond_as_a_BMP_in_the_MIDS_calculator#Pollutant_Reduction). If an iron-enhanced pond bench is included, an additional 40 percent credit is given for dissolved phosphorus. Use the lower values if no iron bench exists and the higher value if an iron bench exists.

[6]Lower values are for Tier 1 design. Higher values are for Tier 2 design.

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Factors affecting pollutant removal

Pollutant removal is affected by several factors. Some of these are briefly discussed below.

- **Influent concentration**. Pollutant removal, as a percent, typically increase as pollutant concentration increases, up to some limiting value. At low **influent** concentrations, pollutant removal may be low since their is likely a limiting concentration below which pollutants can not be effectively removed (often called an irreducible concentration).
- **Maintenance**. Pollutant removal decreases if bmps are not properly maintained.
- **Design**. Practices that are **undersized** typically remove less pollutant, as a percent of influent, while oversized practices may remove more pollutant.
- **Characteristics of the pollutant**. Bmps typically rely on a specific pollutant removal mechanism. Pollutants in runoff are typically more effectively treated by one mechanism versus another. For example, **filtration** (https://stormwater.pca.state.mn.us/index.php?title=Filtration) practices remove sediment and associated pollutants effectively when pollutants are is suspension, but do no effectively remove dissolved pollutants.

Links to tables in the Minnesota Stormwater Manual

Below are links in this manual to information on pollutants removal. Note that the table shown above represents recommended median values, while information in the following links may show ranges of data or information from other sources. The information in these tables therefore represents additional information that can be used for your specific situation rather than the recommended values shown in the table above.

By pollutant

- BMP pollutant removal for phosphorus

- BMP pollutant removal for bacteria
- BMP pollutant removal for hydrocarbons
- BMP pollutant removal for metals
- BMP pollutant removal for total nitrogen
- BMP pollutant removal for total suspended solids

By BMP

- Median pollutant removal percentages for BMPs
- Pollutant removal percentages for filtration BMPs
- Pollutant removal percentages for stormwater pond BMPs
- Examples of the estimated pollutant load reductions for a stormwater reuse storage system sized for the average storm event runoff volume
- Summary of pollutant removal efficiencies in wet stormwater ponds/stormwater wetlands

Links to credit sections in the Minnesota Stormwater Manual

- Calculating credits for permeable pavement
- Calculating credits for iron enhanced sand filter
- Calculating credits for green roofs
- Calculating credits for tree trenches and tree boxes
- Calculating credits for bioretention
- Calculating credits for sand filter
- Calculating credits for stormwater ponds
- Calculating credits for stormwater wetlands

Links to additional information on pollutant removal

- National Pollutant Removal Performance Database (https://owl.cwp.org/mdocs-posts/fraley-mcneall-_national_pollutant_removal_perf_v3/)
- International Stormwater Best Management Practices (BMP) Database (https://bmpdatabase.org/) Pollutant Category Summary Statistical Addendum: TSS, Bacteria, Nutrients, and Metals
  - Compilation of BMP performance studies published through 2011
  - Provides values for TSS, Bacteria, Nutrients, and Metals
  - Applicable to grass strips, bioretention, bioswales, detention basins, green roofs, manufactured devices, media filters, porous pavements, wetland basins, and wetland channels
- The Illinois Green Infrastructure Study (http://www.epa.state.il.us/green-infrastructure/docs/draft-final-report.pdf)
  - Figure ES-1 summarizes BMP effectiveness
  - Provides values for TN, TSS, peak flows / runoff volumes
  - Applicable to permeable pavements, constructed wetlands, infiltration, detention, filtration, and green roofs
- New Hampshire Stormwater Manual (https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/wd-08-20b.pdf)
  - Volume 2, Appendix B summarizes BMP effectiveness
  - Provides values for TSS, TN, and TP removal
  - Applicable to basins and wetlands, stormwater wetlands, infiltration practices, filtering practices, treatment swales, vegetated buffers, and pre-treatment practices
- Design Guidelines for Stormwater Bioretention Facilities (https://publications.aqua.wisc.edu/product/design-guidelines-for-stormwater-bioretention-facilities/). University of Wisconsin, Madison
  - Table 2-1 summarizes typical removal rates
  - Provides values for TSS, metals, TP, TKN, ammonium, organics, and bacteria

  - Applicable for bioretention
- BMP Performance Analysis (https://www3.epa.gov/region1/npdes/stormwater/tools/BMP-Performance-Analysis-Report.pdf). Prepared for US EPA Region 1, Boston MA.
  - Appendix B provides pollutant removal performance curves
  - Provides values for TP, TSS, and zinc
  - Pollutant removal broken down according to land use
  - Applicable to infiltration trench, infiltration basin, bioretention, grass swale, wet pond, and porous pavement
- Weiss, P.T., J.S. Gulliver and A.J. Erickson. 2005. The Cost and Effectiveness of Stormwater Management Practices: Final Report (http://www.lrrb.org/media/reports/200523.pdf)
  - Table 8 and Appendix B provides pollutant removal efficiencies for TSS and P
  - Applicable to wet basins, stormwater wetlands, bioretention filter, sand filter, infiltration trench, and filter strips/grass swales
- Efficiency of Urban Stormwater Best Management Practices: A Literature Review (https://apps.ecology.wa.gov/publications/documents/0703009.pdf)

2008 study on recommended approach to estimating pollutant removal for TSS and TP

In 2008 we conducted a study of several databases and data compilations to develop expected performance measures for Total Suspended Solids (TSS) and Total Phosphorus (TP) for the following categories of BMPs:

- bioretention;
- filtration;
- infiltration;
- stormwater ponds; and
- stormwater wetlands.

This study provided information across a range of designs. We've utilized this information to develop recommended values for pollutant removal across this range of design levels. However, this information should be used with caution as it is somewhat dated now.

The following studies were used to develop these performance measures.

- International Stormwater Best Management Practices (BMP) Database (https://bmpdatabase.org/): This project began in 1996 under a cooperative agreement between the American Society of Civil Engineers (ASCE) and the U.S. Environmental Protection Agency (USEPA). It now has additional support and funding from the Water Environment Research Foundation (WERF), ASCE Environmental and Water Resources Institute, Federal Highway Administration, and the American Public Works Association (APWA). Wright Water Engineers, Inc. and GeoSyntec Consultants maintain and operate the database clearinghouse and web page. Data from well screened BMP studies from throughout the world continues to be entered. Data were downloaded from the website in February 2007 and were summarized for this current evaluation. This database will hereafter be referred to as the ASCE/EPA database.
- Stormwater Assessment Monitoring and Performance Program (https://sustainabletechnologies.ca/about-step/about-swamp/#:~:text=The%20Stormwater%20Assessment%20Monitoring%20and,Association%2C%20along%20with%20host%20municipalities) (SWAMP): SWAMP operated from 1995 to 2003. This program was an initiative of the Government of Canada's Great Lakes Sustainability Fund, the Ontario Ministry of Environment and Energy, the Toronto and Region Conservation Authority, and the Municipal Engineer's Association. This program is attractive to Minnesota because of the attention paid to cold climate conditions. The SWAMP report (SWAMP 2005) summarizes BMP monitoring data, but does not contain raw data. This program will hereafter be referred to as the SWAMP program.
- National Pollutant Removal Performance Database for Stormwater Treatment Practices (http://www.stormwatercenter.net/Library/STP-Pollutant-Removal-Database.pdf), 2nd Edition, March 2000, Center for Watershed

Protection (CWP). This report (Winer 2000) summarizes BMP monitoring data, but does not contain raw data. This report will hereafter be referred to as the CWP report.
- The Cost and Effectiveness of Stormwater Management Practices (http://conservancy.umn.edu/bitstream/11299/986/1/200523.pdf): Report prepared by authors from the University of Minnesota and Valparaiso University and published by the Minnesota Department of Transportation (Mn/DOT) in 2005. This report uses several BMP studies and examines performance relative to costs. This report cited as (Weiss et al. 2005) will be referred to as the Mn/DOT report.

Recommended Performance Measures

BMP performance can be evaluated in several ways, the most common of which are pollutant outflow concentration and pollutant percent removal.

- Pollutant outflow concentration is expressed as the pollutant concentration in the BMP outflow.
- Pollutant percent removal (or removal efficiency) is expressed as the percent change in pollutant load at the outflow relative to the inflow.
- Pollutant percent removal (or removal efficiency) is expressed as the percent change in pollutant concentration of the outflow relative to the inflow.

The first of these measures, pollutant outflow concentration, is the best measure of water quality. It provides an indication of how closely stormwater runoff is to meeting water quality standards (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/assessment-and-listing/water-quality-assessment-and-listing.html), which are concentration based.

The second measure, percent removal expressed as a load, is the most widely used approach. This measure is most applicable when attempting to quantify load reductions, such as for assessing compliance with **total maximum daily load** (https://stormwater.pca.state.mn.us/index.php?title=Total_Maximum_Daily_Loads_(TMDLs)) requirements. However, caution must be used when applying this method. Pollutant removal efficiencies typically are greater when pollutant concentrations are higher. For example, using data from the ASCE/EPA database, at low influent TSS concentrations (less than 100 milligrams per liter), percent removals in stormwater ponds range from 0 percent to almost 100 percent. At higher influent concentration (greater than 100 milligrams per liter), percent removals are greater than 80 percent.

Caution: In taking a credit for a BMP based on percent pollutant removal, be aware that removal efficiency is a function of pollutant concentrations in stormwater entering the BMP

The third measure, percent removal based on pollutant concentration, is not recommended. When percent removal is based solely on concentrations, water volume is ignored, when in fact it could be markedly influencing the performance of the BMP. For example, if a large volume of heavily concentrated pollution is entering a bioretention BMP and much of the water is infiltrating into the ground, the overall load will be greatly reduced, yet not show up as such if the outflow concentration remains high.

Inflow concentration should be examined and considered in the analysis. If inflow concentration is already quite low, and if pollutant percent removal is also low, the low percent removal may partly be due to the fact that additional pollutant removal is not currently technologically possible, a concept known as the “irreducible concentration.”

Another important factor that must be incorporated into every BMP performance assessment is the limitation to only water that actually flows into and through the treatment system. Any flow that exceeds the design specifications for the BMP should be by-passed or diverted and not included in the treatment efficiency calculations. Instead, this flow should be routed to a receiving water as “untreated” or preferably routed to another BMP for subsequent treatment.

BMP Performance

The majority of the BMP performance data was taken from the ASCE/EPA database, the CWP report, and the Mn/DOT report. These studies were comprehensive data gathering efforts and analyses with a high level of quality control. However, the data are not all directly comparable due to different statistics being presented in the different sources. Medians and interquartile ranges of outflow concentrations were available in the ASCE/EPA database, and percent reductions (based on event mean concentrations) were calculated using the database. In the CWP report, the medians were presented in tables, but the interquartile ranges were estimated from graphic presentations of the data. Percent removal data in the CWP report are based on either load or concentration, but that distinction for each BMP was not noted. The Mn/DOT study only reported means.

In the percent removal data, the 75th percentile represents the high tier of BMP performance, the median represents the middle tier, and the 25th percentile represents the low tier. The opposite is true for the outflow concentration data, in that the 25th percentile represents the high tier of expected BMP performance, since low outflow concentration suggests high performance, and high outflow concentration suggests low performance.

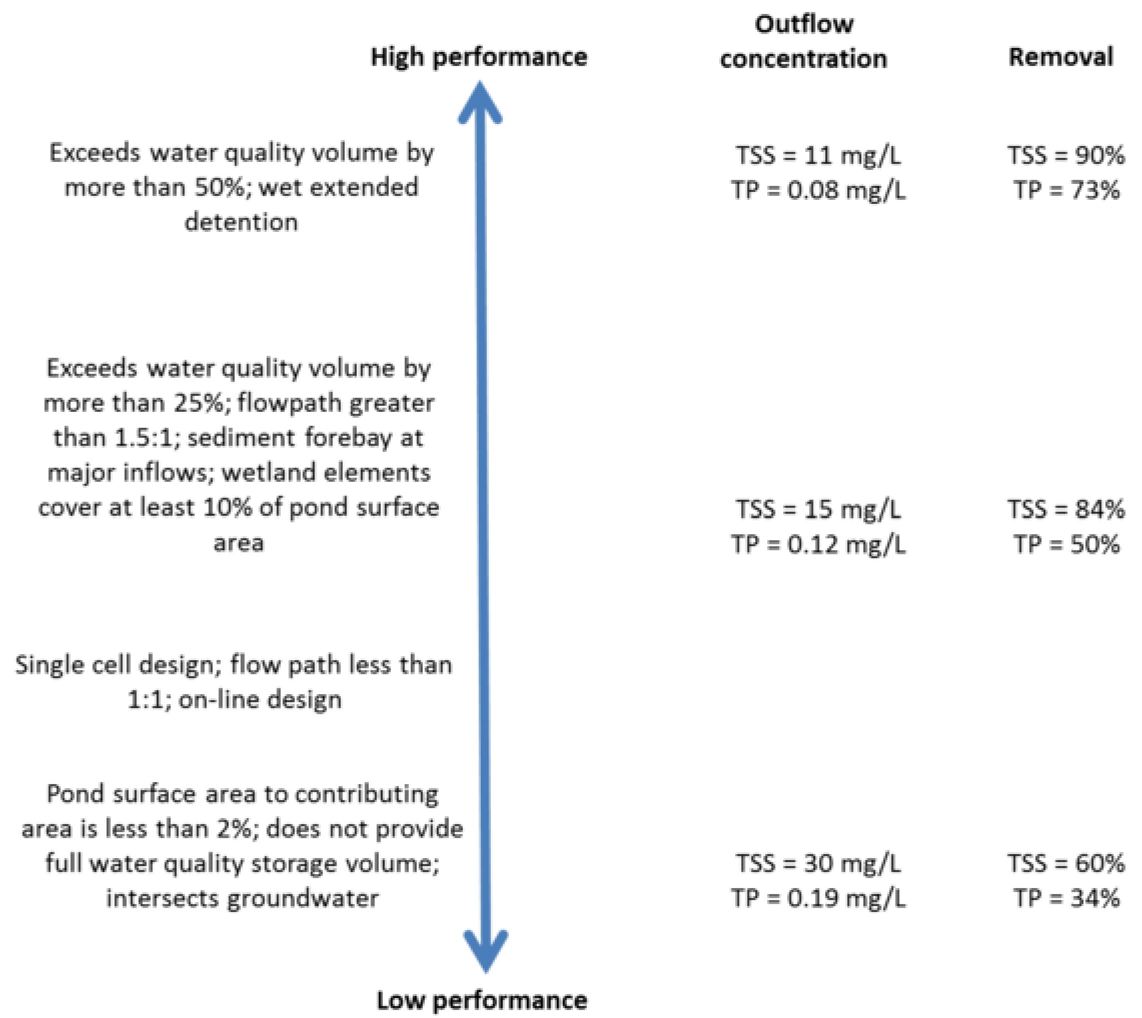
The comparisons presented here are from a visual examination of the data; they do not represent statistically significant differences among the groups, which was not possible to test due to the fact that we did not have all of the raw data. Data from bioretention devices and infiltration practices are not included in the following figures due to a lack of evaluation data, but they are discussed in the appropriate section below.

All BMPs combined

When using these data to estimate the performance of a specific BMP, the estimate should be selected based on the design elements shown in the figures for each BMP. If the installation shows neither positive nor negative elements as listed in the design elements figures, the median (50th percentile) should be used. For example, in a stormwater pond, the outflow TSS concentration that could be expected under most conditions would be about 15 milligrams per liter. If there are positive design elements, it would be lowered to approximately 11 milligrams per liter, and if there were negative design elements, the expected outflow concentration would be raised to approximately 30 milligrams per liter. Data from the Mn/DOT report are presented in the tables in this section, even though they present only means and not interquartile ranges. The Mn/DOT study incorporated some of the same studies that the CWP database includes; it is therefore presented simply to show its value compared to the currently reported ASCE/EPA and CWP values.

- Median TSS outflow concentrations ranged from 13 to 26 milligrams per liter and median/mean percent removals ranged from 54 percent to 88 percent.
- The lowest TSS outflow concentration and highest percent removal of TSS were achieved by media filters, at approximately 10 milligrams per liter and 85 percent, respectively.
- Percent removal in stormwater ponds was similar to that in media filters, but the interquartile range was larger in the pond data.
- TSS percent removal in grass filters differed between the CWP and ASCE/EPA databases, with median percent removals at 81 percent and 54 percent, respectively, and with interquartile ranges not overlapping. However, the TSS interquartile ranges of the two databases showed large overlap in the outflow concentration data. Because of the number of studies and scrutiny placed on the character of the data collection, use of the ASCE/EPA database is preferred.
- Grass filters performed the poorest among the BMP categories for TP treatment, with median outflow concentrations ranging from 0.19 to 0.29 milligrams per liter, and median/mean percent removals ranging from 35 to 41 percent.

Stormwater ponds



Schematic of design elements affecting stormwater pond performance

Information on TSS and TP outflow concentrations and removal percentages for stormwater pond practices are shown in the figure to the right and the table below. Median outflow concentrations were 13 and 17 milligrams per liter for TSS and 0.13 and 0.11 milligrams per liter for total phosphorus for the ASCE/EPA and the CWP studies, respectively. Median removal percentages for the two studies were 88 and 80 percent for TSS and 48 and 51 percent for total phosphorus. For standard designs that meet recommended specifications, TSS removal is estimated at 84 percent and TP removal is 50 percent. If 55 percent of TP was in particulate form, the expected removal would be 46 percent. This is close to but less than the median value of 50 percent. Stormwater ponds are generally not considered to be effective at retaining dissolved phosphorus.

Information: For standard designs that meet recommended specifications, TSS removal is estimated at 84 percent and TP removal is 50 percent

Greater removal percentages may be applied when the design water quality volume is exceeded by more than 25 percent, wet extended detention or multiple pond design is used, off-line design is used, the flow path is greater than 1.5:1, sediment forebays are utilized at major inflows, or wetland elements cover at least 10 percent of the surface area of the pond. Lower pollutant removal occurs when the full water quality volume is not provided, a single cell design is used, when the pond intersects groundwater, when the flow path is less than 1:1, when on-line design is utilized, or when the wetland surface area to contributing area is less than 2 percent.

Stormwater pond outflow concentrations and pollutant removals.
Link to this table

Source	TSS outflow concentration (mg/L) at a given Percentile	TP outflow concentration (mg/L) at a given Percentile

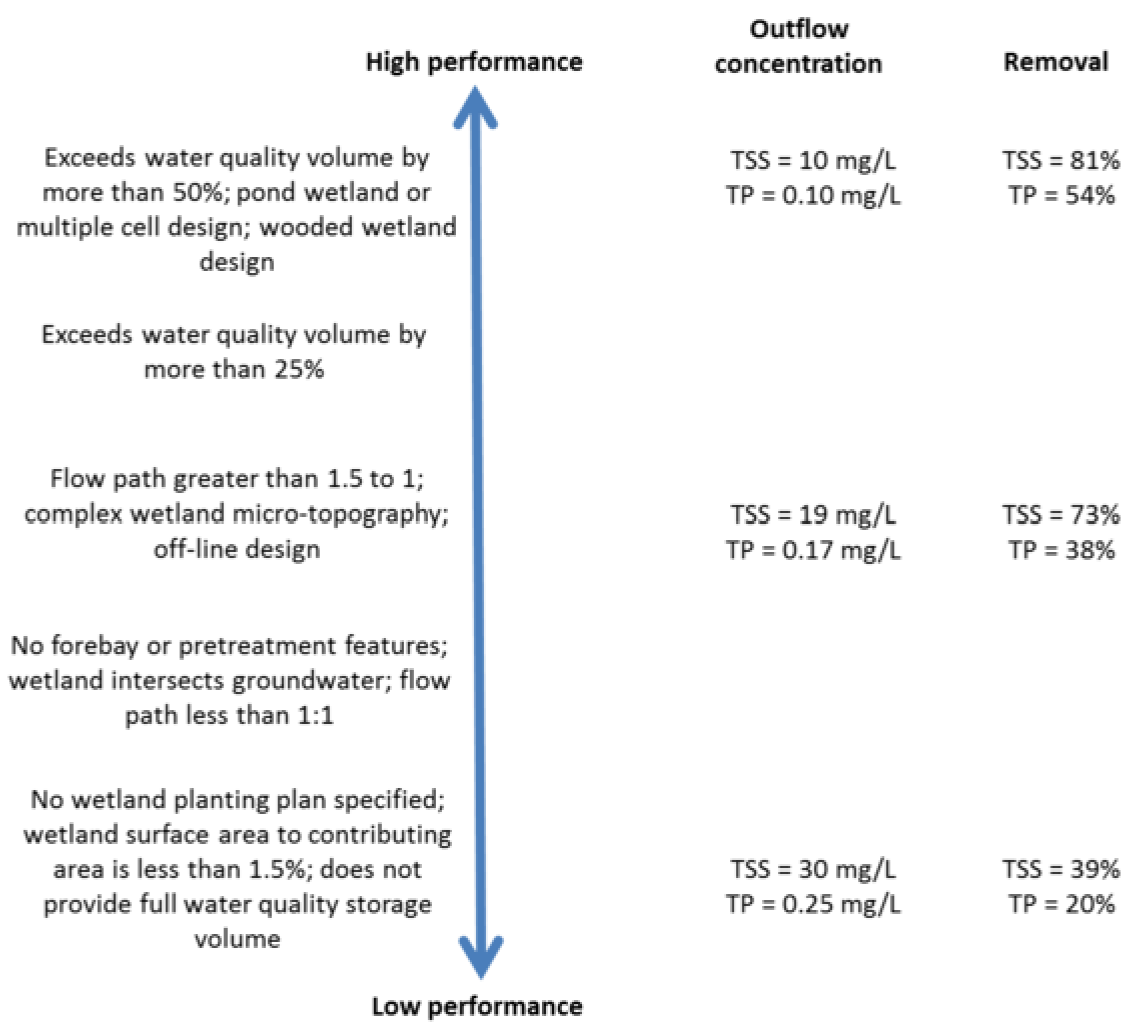
Source	TSS outflow concentration (mg/L) at a given Percentile			TP outflow concentration (mg/L) at a given Percentile		
	25th	50th	75th	25th	50th	75th
ASCE/EPA	11	13	25	0.08	0.13	0.20
CWP	11	17	34	0.07	0.11	0.17

Source	TSS Percent Removal at a given Percentile[1]			TP Percent Removal at a given Percentile[1]		
	25th	50th	75th	25th	50th	75th
ASCE/EPA	60	88	94	29	48	69
CWP	60	80	86	39	51	76

[1]MnDOT values for mean TSS removal=65% and mean TP removal=52%

Stormwater wetlands

Information on TSS and TP outflow concentrations and removal percentages for stormwater wetland practices are shown in the figure to the right and the table below. Median outflow concentrations were 15 and 22 milligrams per liter for TSS and 0.13 and 0.20 milligrams per liter for total phosphorus for the ASCE/EPA and the CWP studies, respectively. Median removal percentages for the two studies were 70 and 76 percent for TSS and 27 and 49 percent for total phosphorus. For standard designs that meet recommended specifications, TSS removal is estimated at 73 percent and TP removal is 38 percent. If 55 percent of TP was in particulate form, the



Schematic of design elements affecting stormwater wetland performance

expected removal would be 40 percent. This is close to the median value of 38 percent. Stormwater wetlands are not considered to be effective at removing dissolved phosphorus and in some cases may contribute to dissolved phosphorus loads.

Information: For standard designs that meet recommended specifications, TSS removal is estimated at 73 percent and TP removal is 38 percent

Greater removal percentages may be applied when the design water quality volume is exceeded by more than 25 percent, a pond wetland or multiple cell design is utilized, or a wooded wetland design is used. Lower pollutant removal occurs when the full water quality volume is not provided, when no forebay or pretreatment features are used, when the wetland intersects groundwater, when the flow path is less than 1:1, when no wetland planting plan is specified, or when the wetland surface area to contributing area is less than 1.5 percent.

Stormwater wetland outflow concentrations and pollutant removals.
Link to this table

Source	TSS outflow concentration (mg/L) at a given Percentile			TP outflow concentration (mg/L) at a given Percentile		
	25th	50th	75th	25th	50th	75th
ASCE/EPA	9	15	26	0.07	0.13	0.25
CWP	11	22	33	0.12	0.20	0.25

Source	TSS Percent Removal at a given Percentile[1]			TP Percent Removal at a given Percentile[1]		
	25th	50th	75th	25th	50th	75th
ASCE/EPA	28	70	75	16	27	32
CWP	49	76	86	23	49	76

[1]MnDOT values for mean TSS removal=68% and mean TP removal=42%

Filtration practice (grass filters/swales)

Information on TSS and TP outflow concentrations and removal percentages for grass filtration practices (swales) are shown in the figure to the right and the table below. Median outflow concentrations were 26 and 14 milligrams per liter for TSS and 0.29 and 0.19 milligrams per liter for total phosphorus for the ASCE/EPA and the CWP studies, respectively. Median removal percentages for the two studies were 54 and 81 percent for TSS and -35 and 34 percent for total phosphorus. For standard designs that meet recommended specifications, TSS removal is estimated at 68 percent and TP removal is 0 percent. Note that the results for TP are highly variable, particularly for the ASCE/EPA study.

Information: For standard designs that meet recommended specifications, TSS removal is estimated at 68 percent and TP removal is 0 percent

Greater removal percentages may be applied when the design water quality volume is exceeded by more than 25 percent. Removal of phosphorus can be achieved if amendments such as iron are added to the filter media (see Iron enhanced sand filter (Minnesota Filter)). Lower pollutant removal occurs when the full water quality volume is not provided, when on-line design is used with no storm bypass, when no pretreatment is used, when swale slopes are too great or small, when swale side slopes are too steep, or when soil infiltration rates are low.

Stormwater filtration practice (grass filters/swales) outflow concentrations and pollutant removals.
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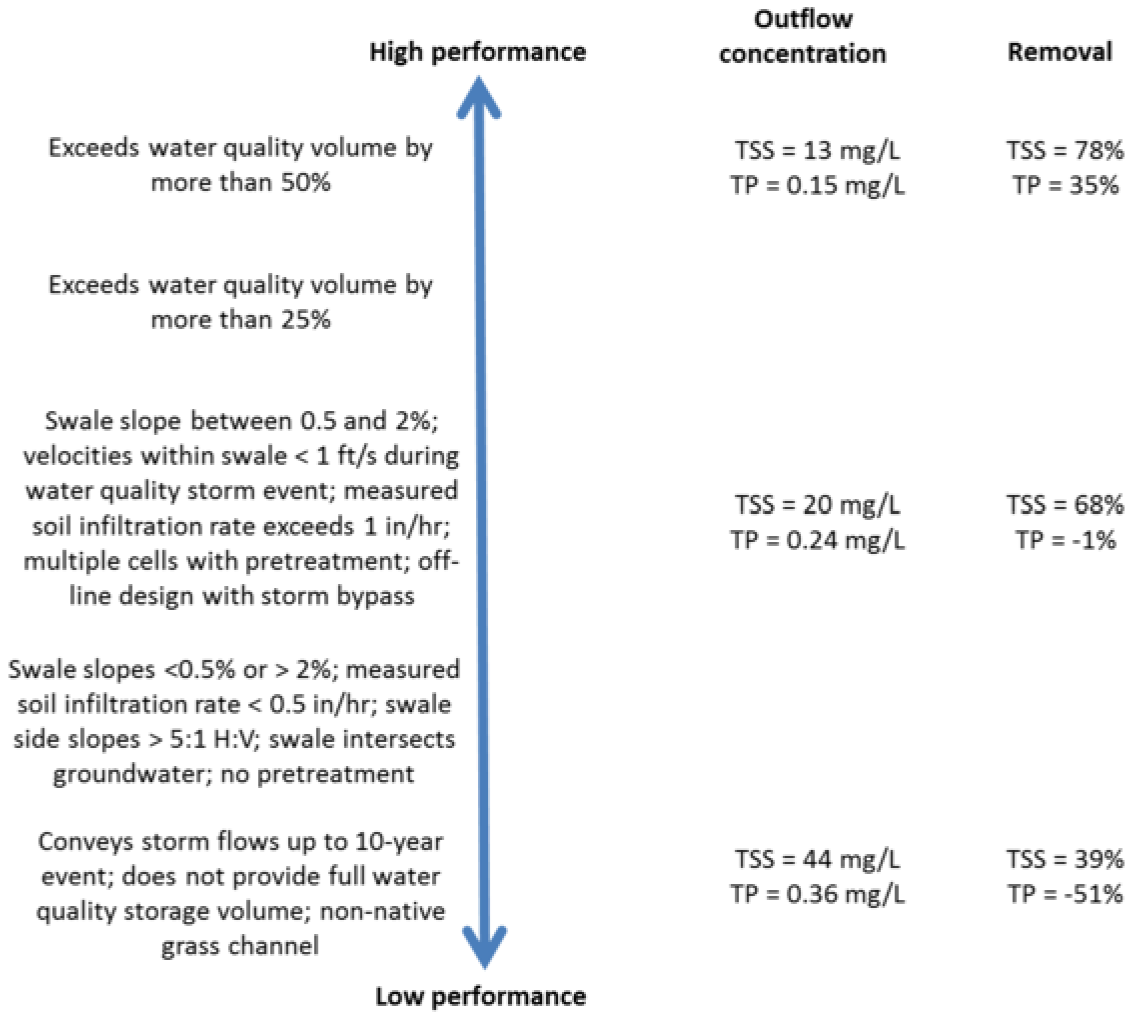


Schematic of design elements affecting grass filter performance

Source	TSS outflow concentration (mg/L) at a given Percentile			TP outflow concentration (mg/L) at a given Percentile		
	25th	50th	75th	25th	50th	75th
ASCE/EPA	18	26	53	0.19	0.29	0.46
CWP	8	14	35	0.11	0.19	0.26

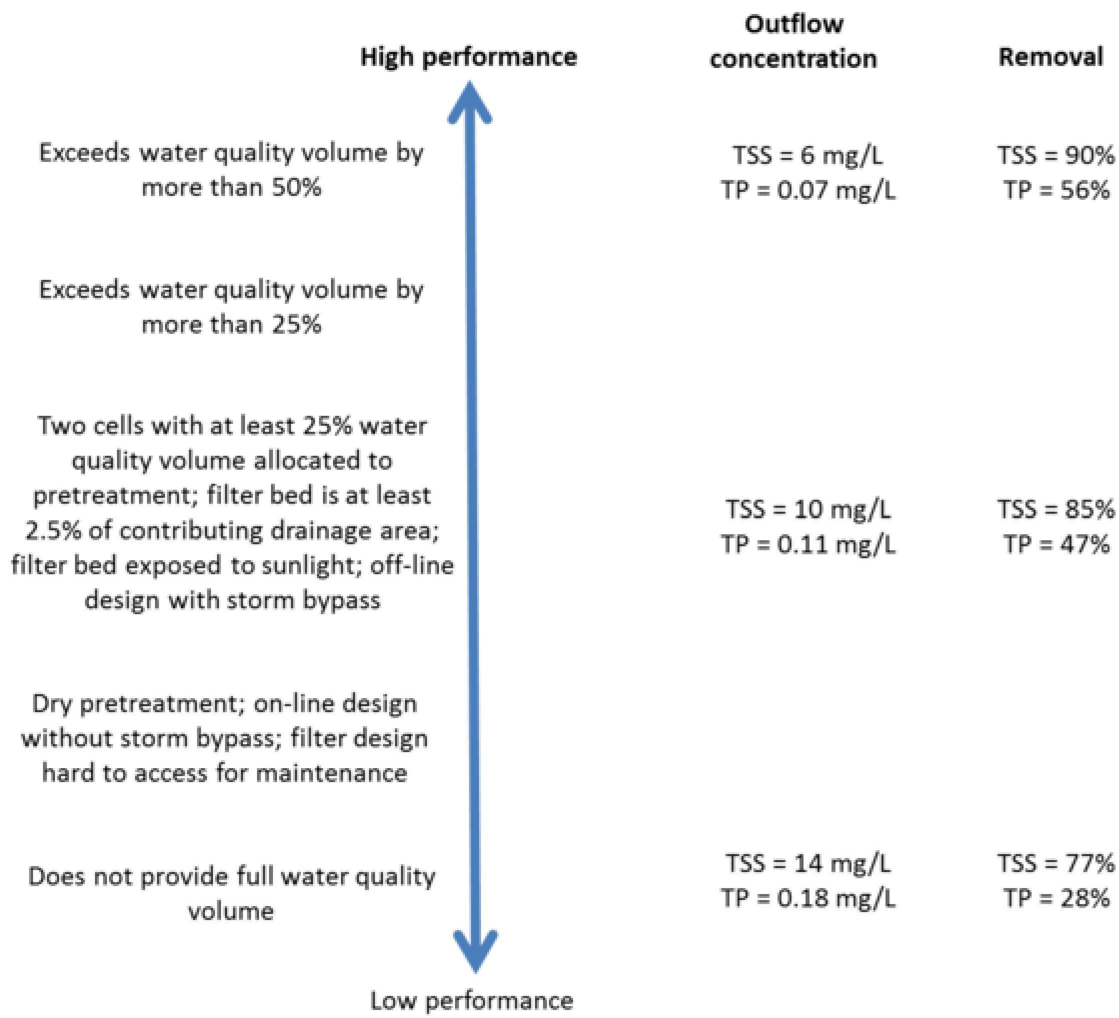
Source	TSS Percent Removal at a given Percentile[1]			TP Percent Removal at a given Percentile[1]		
	25th	50th	75th	25th	50th	75th
ASCE/EPA	8	54	70	-121	-35	15
CWP	70	81	86	19	34	54

[1]MnDOT values for mean TSS removal=68% and mean TP removal=41%

Filtration practice (media filters/sand filters/peat mixed with sand/other)

Information on TSS and TP outflow concentrations and removal percentages for filtration practices are shown in the figure to the right and the table below. Median outflow concentrations were 8 and 11 milligrams per liter for TSS and 0.11 and 0.10 milligrams per liter for total phosphorus for the ASCE/EPA and the CWP studies,

respectively. Median removal percentages for the two studies were 83 and 86 percent for TSS and 35 and 59 percent for total phosphorus. For standard designs that meet recommended specifications, TSS removal is estimated at 85 percent and TP removal is 47 percent. Assuming that all the phosphorus is particulate, this corresponds with 55 percent of the total phosphorus being associated with sediment (0.85 * 0.55 * 100 percent = 47 percent).



Schematic of design elements affecting filter media performance

Information: For standard designs that meet recommended specifications, TSS removal is estimated at 85 percent and TP removal is 47 percent

Greater removal percentages may be applied when the design water quality volume is exceeded by more than 25 percent. Greater removal of phosphorus can be achieved if amendments such as iron are added to the filter media (see Iron enhanced sand filter (Minnesota Filter)). Lower pollutant removal occurs when the full water quality volume is not provided, when on-line design is used with no storm bypass, when dry pretreatment is used, or when the BMP is not adequately maintained.

Stormwater filtration practice (media filters; includes sand filters, peat mixed with sand, and other) outflow concentrations and pollutant removals.
Link to this table

Source	TSS outflow concentration (mg/L) at a given Percentile			TP outflow concentration (mg/L) at a given Percentile		
	25th	50th	75th	25th	50th	75th
ASCE/EPA	6	8	12	0.08	0.11	0.16
CWP	5	11	16	0.06	0.10	0.19

Source	TSS outflow concentration (mg/L) at a given Percentile			TP outflow concentration (mg/L) at a given Percentile		
	25th	50th	75th	25th	50th	75th

Source	TSS Percent Removal at a given Percentile[1]			TP Percent Removal at a given Percentile[1]		
	25th	50th	75th	25th	50th	75th
ASCE/EPA	73	83	87	15	35	47
CWP	80	86	92	41	59	65

[1]MnDOT values for mean TSS removal=82% and mean TP removal=46%

Bioretention

Performance data from bioretention devices are less available than data for the other BMP types. Since inflow often does not enter bioretention devices through a channel, it is difficult to monitor. More importantly, bioretention devices are often designed to infiltrate stormwater, and therefore do not always overflow. In a USGS study on the effects on water quality of rain gardens in the Twin Cities metropolitan area, two of the five studied rain gardens did not overflow at all during the study's time period (Tornes, 2005) and therefore retained all of the incoming TSS and TP loads. At sites where overflow did occur, the pollutant concentrations in the outflow were generally lower than the concentrations in the inflow. Effluent concentrations from bioretention BMPs with an underdrain range from 0.04 to 0.35 milligrams per liter with a mean of 0.16 milligrams per liter. However, since volumes were not monitored it was not possible to estimate what percent of the pollutant loads were retained. TSS was not monitored in that study, and TSS data for bioretention devices are not included in the CWP report; therefore only TP values were presented.

In a study on the Burnsville rain gardens in the Twin Cities Metropolitan area, there was an 82 percent reduction in annual stormwater runoff over a two-year monitoring period, with a greater than 95 percent reduction in volume for many storms (Yetka and Leuthold, 2005). Other local data, from the H.B. Fuller Company bioretention system, show a 73 percent reduction in stormwater volume, a 94 percent reduction in particulates, and a 70 percent reduction in TP. However, the soluble fraction of phosphorus in the runoff increased by 70 percent (Langer, 1997). Interpretation of the performance data presented here for bioretention is somewhat inconclusive due to the methods used and the low number of documented studies. Bioretention devices are highly effective at removing TSS and TP loads when they infiltrate the majority of the volume of stormwater runoff events.

Phosphorus removal percentages for bioretention BMPs can be calculated from the following table.

Phosphorus credits for bioretention systems with an underdrain. This includes tree trenches and dry swales.
Link to this table

Particulate phosphorus (PP)	Dissolved phosphorus (DP)

Particulate phosphorus (PP)

Is Media Mix C or D being used or, if using a mix other than C or D, is the media phosphorus content 30 mg/kg or less per the Mehlich 3 (or equivalent) test[1]?

- If yes, particulate credit = 100% of the particulate fraction (assumed to be 55% of total P)
- If no or unknown, particulate credit = 0%

The assumption of 55 percent particulate phosphorus and 45 percent dissolved phosphorus is likely inaccurate for certain land uses, such as industrial, transportation, and some commercial areas. Studies indicate particulate phosphorus comprises a greater percent of total phosphorus in these land uses. It may therefore be appropriate to modify the above equation with locally derived ratios for particulate and dissolved phosphorus. For more information on fractionation of phosphorus in stormwater runoff, link here (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_and_dissolved_phosphorus_in_stormwater_runoff#Ratios_of_particulate_to_dissolved_phosphorus).

Example PP removal credit

- Particulate fraction (55% of TP) * removal rate for that fraction (80% for bioretention and tree trench and 68% for swale main channel) = 0.55 * 0.80 = 0.44 or 44% for bioretention and tree trench (with underdrain) and 0.55 * 0.68 or 36% for swale main channel (with underdrain)
- If particulate is 75% of TP, removal = 0.75 * 0.80 or 60% for bioretention and tree trench (with underdrain) and 0.75 * 0.68 or 51% for dry swale

Dissolved phosphorus (DP)

1. Is Media Mix C or D being used or, if using a mix other than C or D, is the media phosphorus content 30 mg/kg or less per the Mehlich 3 (or equivalent) test[1]?

- If yes, credit as a % (up to a maximum of 20%) = 20 * (depth of media above underdrain, in feet/2)
- If no or unknown, credit = 0%

2. Does the system include approved P-sorbing soil amendments[2]?

- If yes, additional 40% credit

Example DP removal credit

- DP removal if dissolved credit is 20% = Dissolved fraction (45%) * removal rate for that fraction (20%) = 0.09 or 9 percent
- Adjust DP removal if depth is less than 2 feet. Example depth = 1 foot then DP removal = 0.45 * 10% * 1/2 = 0.045
- Adjust DP removal if dissolved credit is higher due to use of P-sorbing soil amendments
- Adjust if the fraction (percentage) of DP is different than 45%

The assumption of 55 percent particulate phosphorus and 45 percent dissolved phosphorus is likely inaccurate for certain land uses, such as industrial, transportation, and some commercial areas. Studies indicate particulate phosphorus comprises a greater percent of total phosphorus in these land uses. It may therefore be appropriate to modify the above equation with locally derived ratios for particulate and dissolved phosphorus. For more information on fractionation of phosphorus in stormwater runoff, link here (https://stormwater.pca.state.mn.us/index.php?title=Event_mean_concentrations_of_total_and_dissolved_phosphorus_in_stormwater_runoff#Ratios_of_particulate_to_dissolved_phosphorus).

TP removal = PP removal + DP removal

[1]Other widely accepted soil P tests may be used. Note: a basic conversion of test results may be necessary

[2]Acceptable P sorption amendments include

- 5% by volume elemental iron filings above IWS or elevated underdrain
- minimum 5% by volume sorptive media above IWS or elevated underdrain
- minimum 5% by weight water treatment residuals (WTR) to a depth of at least 10 cm
- other P sorptive amendments with supporting third party research results showing P reduction for at least 20 year lifespan, P credit commensurate with research results

Infiltration

Due to similar difficulties as those that exist with monitoring bioretention systems, there are few data available demonstrating the load reductions or outflow concentrations of larger-scale infiltration practices such as infiltration trenches. Few sampling programs collect infiltrating water that flows through an infiltration system. For properly designed, operated, and maintained infiltration systems, all water routed into them should be "removed" from stormwater flow, resulting in 100 percent efficiency relative to volume and pollutant reduction. For this reason, performance tables similar to those above would only reflect this performance. This logic assumes that stormwater is the beneficiary of any infiltration system, but ignores the fact that pollution, if any remains after the internal workings of the infiltration BMP itself, is being transferred into the shallow groundwater system. Good monitoring data on the groundwater impact of infiltrating stormwater are rare, but there are efforts underway today to document this, so future Manual revisions should be able to include some data updates.Properly designed infiltration systems will accommodate a design volume based on the required water quality volume. Excess water must be by-passed and diverted to another BMP so that the design infiltration occurs within 48 hours if under state regulation, or generally within 72 hours under certain local and watershed regulations. In no case should the by-passed volume be included in the pollutant removal calculation. Data that are reported in performance literature for infiltration systems, unless reporting 100 percent effectiveness for surface water or documenting outflow water downward, are not accurately representing behavior, or are representing the excess flow (overflow) from a system. Design specifications should prevent putting excess water beyond that which will infiltrate within the given time frame. Any excess should be diverted away from the infiltration system and reported as inflow to another treatment device.

Extreme caution must be exercised and serious planning undertaken to assure that no highly contaminating material is routed into these BMPs. Of particular concern are toxic organics (gasoline, solvents) and high levels of chloride.

Other Factors Influencing Performance

Even though the ASCE/EPA database is the most comprehensive collection of BMP performance data, there are not enough data points in the database to statistically examine the effect that design parameters have on BMP performance (ASCE/EPA, 2000). The design parameters listed in the BMP performance figures are derived from best professional judgment. There are many other factors that affect the performance of BMPs that have not been discussed in the previous sections. There is little in-depth statistical analysis that can be done for these other factors due to the lack of reported information on them. Nevertheless, it can be stated with certainty that they do have an impact on BMP performance and should, therefore, be considered when designing a practice. Some of these factors include the following:

- geographic location;
- watershed configuration (e.g. size, slope, shape and depth to bedrock or water table);
- uncertainty of hydrologic measurements (e.g. initial losses due to landscape retention, variable runoff coefficients, location of rainfall data recorders and extent of connected imperviousness);
- BMP design criteria (e.g. ratio of permanent and temporary storage to drainage area, storage configuration, drawdown time, length-to-width and bathymetric ratios, soil permeability);
- BMP maintenance; and
- climate.

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